THE RECORD

OF THE

UNITED STATES NAVAL INSTITUTE.

Vol. II. **1876.** **No. 3.**

U. S. NAVAL ACADEMY, ANNAPOLIS,

MARCH 9, 1876.

Professor N. M. TERRY in the Chair.

THE TACTICS OF SUBMARINE TELEGRAPH WORK.

BY PASSED ASSISTANT ENGINEER THOS. W. RAE.

This title has been chosen to define precisely the scope of the paper. No industrial enterprise exacts of its votaries from inception to completion, wider and more thorough knowledge of their respective specialties, than does the uniting of distant countries by a telegraph cable. The statistician, hydrographer, physicist, manufacturer and seaman must all do their utmost possible to avert from the project the disaster that any miscalculation, careless reconnoisance, clumsy workmanship, or inadequate equipment will loudly invite. So much is comprehended in the phrase Submarine Telegraph Work, that in a limited article it will be impossible to dispose of more than a single branch of the subject, with any degree of completeness. To elect this branch is then the question, and, considering each in turn, the choice naturally falls on that of which least has hitherto been said.

The function of the hydrographer in cable-work is not different from what it is in connection with other undertakings, the electrician's researches are clearly and learnedly set forth in various published works upon the subject; but the processess of the factory, the routine of laying the finished cable, both of which exhibit how far practical restraints modify abstract theoretical conclusions—these are unknown, and their importance demands honorable recognition in the group of technisms already specified. It is not he who dreams of the possible utilization of some one of nature's forces, whom posterity will enshrine, but rather he who impresses and disciplines this force until it seems to have no purpose but to do man's bidding. Some pre-historic Chinese experimenter and Hero of Alexandria, no doubt did boil water, and

drive curious toys thereby, but until Newcomen drained the Cornish mines with it, the Steam Engine cannot be said to have had an existence. Motion under electrical influence has been recognized as far back as natural philosophers have recorded their investigations, and many, among whom Schilling, Gauss and Weber are notable, have considered its application to telegraphy: but until Cooke, Wheatstone, Steinheil and Morse had patiently and unremittingly sought for and found a way around this obstacle, had neutralized that incompatible quality, had simplified and cheapened apparatus and material until suitable for common use—the Electric Telegraph had no real life. Who first conceived the idea of crossing the ocean with a telegraph cable, cannot be named, but they who did it first are subjects of history; and the aim of this article is to tell the methods and devices resorted to by these adventurous and ingenious spirits and their successors, which gave birth to Ocean Telegraphy and have so developed it that the laying of a new cable excites little more notice than the passage of a mail steamer.

Having said thus much to illustrate the propriety of the caption, it may be of interest to glance at considerations which influence the putting down of a telegraph cable as a commercial enterprise. The reproach of mad speculation, that not without show of justice was urged against the originators of the first scheme for spanning the Atlantic, has, in these latter days, quite lost point. The undertakings have been uniformly successful, and the close scrutiny so long maintained of the conditions under which cables work remuneratively, has embodied a system of principles by which one may very closely predicate the result of a scheme of this nature. While the thoughtful cannot but be impressed with the boldness and faith of those who hazarded their fortunes on the success of a cable of unprecedented length across the only guessed-at bed of a stormy ocean, it must be understood that they did not argue from incomplete or insufficient premises—for, as early as 1851, France and England were in electrical communication underneath the Channel; and two years later, England and Belgium, under the German Ocean. Then Scotland and Ireland were united, next England and Holland, and during this same time Prince Edward's Island was connected with the main land, and a short cable put down in the Baltic Sea, between Korsoe on the Island of Zealand, and Vyberg. The cables of the Black Sea followed, and were a great advance upon preceding ones, not only as regards length, which was all together three hundred and fifty miles, but also on account of nearly half the

circuit's being of that rarely satisfactory type of cable, viz. unarmored, except at the shore-ends. This line connected Varna, Balaklava and Constantinople, and was an outgrowth of the Crimean war. Europe and Africa were next united, first by cables from Spezzia to Corsica and Sardinia, one hundred and twenty miles in total length, and later, after repeated disasters, by a line from Cape Spartivento to Bona, near Tunis, one hundred and twenty five miles long.

During this time a second attempt to span the Gulf of St. Lawrence proved successful; and in 1857, Sardinia, Malta and Corfu were joined by cables of an aggregate length of seven hundred and seventy miles. It must not be supposed that the foregoing list is a series of unbroken successes. No less than seven failures occurred in the few schemes mentioned; but they only served to stimulate to greater effort the undaunted Newall, who planned and executed all but one of them. The projectors of the Atlantic cable did not then plunge into the enterprise blindfold, and their experience, combined with all that preceded and all that has followed it for a guide, has made investment in submarine telegraphs as legitimate and conservative a venture as buying Government bonds. Regarded commercially the question is as follows:—

The foreign commerce of the regions which it is proposed to unite amounts to a certain sum annually, and use of telegraphic facilities bears a definite ratio to that amount, as established by many years' observation. A cable of given dimensions—which are limited by length of route, and depth of water—can transmit but so many words a minute. May it then be reasonably expected that the charge per word which will be paid without demur, and which statistics prove to stand in a specific ratio to the interests involved, will pay the expenses of maintenance, and yield stockholders satisfactory dividends, besides accumulating a fund for making good the casualties from which no line is absolutely safe? It is readily seen from the foregoing that about the most important factor in the calculation is the size of the cable which it is practicable to lay, and, as this depends upon careful survey of the route under consideration, the cost of thus much of the enterprise is literally cast upon the waters, in hope of a return after certain days.

The experience upon which these remarks are based was acquired from Florida to Guiana, through the Greater and Lesser Antilles, and across the Caribbean Sea, embracing a variety of ocean bed which perhaps no other equal portion of the globe can show, and for this reason peculiarly full of interest. It is needless here to touch upon the subject of deep-sea soundings, for its latest development may be learned from

the recent valuable reports of the Hydrographic Office, where they are thoroughly and accurately described—and moreover the depth of the ocean has little influence one way or another, in laying a telegraph cable across it. The consideration that really weighs, and which must be most carefully studied, is the nature of the land beneath rather than the depth of water above it. It is a noticeable fact, and one for which there is ample explanation, that the ocean bed at great depths does not present the same asperities of surface encountered on dry land. There are elevations and depressions, hills and valleys—even mountain chains in some localities,—but whether from the constant attrition of currents or the superincumbent weight of water under which they were first thrown up by interior forces, the abruptness which characterizes similar features on dry land does not appear. A recognition of this fact reduces greatly the labor of sounding in mid-ocean, and it is only on approaching land, that more frequent and precise casts are necessary. On the undulating bottom, and in the undisturbed water of lower depths, a cable is practically indestructible, but when pendent between rocky ridges or swayed by currents across the face of a submarine precipice, its rapid destruction is inevitable.

In the open sea only enough soundings need be taken to give a profile sufficiently accurate to reveal the per centum of "slack," as it is termed, which must be allowed at each point of the route to ensure the cable's lying entirely upon the bottom without strain nor yet undue waste. But as the depth lessens, and the cable leaves the region of perpetual calm for that of currents and waves, no method of observation should be neglected; the soundings should be taken as frequently as possible, the lead and specimen cups closely scrutinized, and the nearing shore, carefully scanned, so that by noting the direction of mountain ranges—if such be the nature of the coast—the slope of their sides, the direction and succession of intersecting valleys—an analogue may be obtained of the blind region undergoing exploration. This proceeding will be found of great service—it hints at formations which are often discovered upon actual trial, furnishing in this way a guiding hypothesis for the accurate survey of the landings upon which, as much as upon anything else, the success of a cable, as a piece of engineering depends. The route chosen for the landing must be retired as far from marine highways and anchorages and in as deep water as possible—for the size, weight and cost of the cable are vastly increased amid surroundings where damage from the grounding of a ship or the dragging of an anchor is possible. It is worth while to devote time and

labor to the finding of a secure path for the shore-end of a cable, and to insure that it be laid therein. If the course be sinuous, or attended with abrupt declivities, the trouble of establishing a base line on the shore and erecting beacons at its extremities sufficiently prominent to be visible from any point of the route will be fully repaid, not only at the first laying but in possible future repairing operations. This work done—the quantity, type and dimensions of the cable may be settled upon, and an opinion formed of the feasibility of the scheme. The insulated conductor of all cables is now-a-days substantially the same. Calculation, experiment and, what is better yet, prolonged use have pronounced a loosely laid strand of seven copper wires, whose circumscribing cylinder has a diameter of about 0.15 inches, to be the best for general purposes, and the best dielectric for this strand to be layers of gutta percha closely adhering to the wire and to each other, until its diameter amounts to 0.3 or 0.4 inches. The difference in modern cables lies principally in their armor, which depends almost entirely upon the depth of water in which they are laid. The deep-sea type must be able to sustain its own length for at least the greatest depth along its route, and a large factor of safety is employed to give security in case of unforeseen strains. The weight of average deep-sea cable is between one and two tons per mile. A serving of twisted hemp is interposed between the conductor and its armor to prevent the latter's cutting into the former, and damaging the insulation. Outside the iron armor most modern cables have another serving of yarns, which is the nucleus of a coating of tar and silica that in many cases saves the armor from rapid corrosion. The first cable uniting Cuba and Florida failed for this reason; it lay across patches of a peculiar red mud, presumably oxide of iron, which completely destroyed the wire covering, and this being gone, the Gulf current soon severed the conductor. Some cables include several separate conductors, which, while enlarging the capacity for business, so increase its bulk, that the expedient is only permissible in short circuits. The conductor is made from the purest Lake Superior copper, whose resistance to the passage of currents is least of any of the useful metals, and which, measured in the British Association units or ohms, ranges from four to five per knot.

The reason for employing a twisted strand instead of a single wire is that it may not be parted within the dielectric, by the strain to which the method of putting on the armor renders it liable. Economy of labor and material prescribe that the latter shall be put on in the same manner that wire rope is made, and the elasticity of such a fabrication

necessitates an equally elastic conductor. While it is eminently desirable that the conductor should offer a minimum resistance to current electricity—it is even more necessary that the dielectric should offer the maximum opposition to its escape, and this too is measured in similar units. The ordinary insulation demanded by modern contracts is 300,000,000 ohms per knot, at 75° Fah., because the insulating power of gutta percha varies considerably with pressure and temperature. Another quality exists upon which the rapidity of signalling depends to a very great extent, and which thus far has proved the most obstinate of drawbacks: it is called electro-static or inductive capacity and is measured as readily as resistance, but in other units. The British Association unit of capacity is termed a farad, and each knot of the average deep-sea cable contains about one third of a farad. The less this quantity is, the greater the speed of signalling, and, as it varies with the material and thickness of the insulator, much research has been lavished upon the subject, which has only resulted in a return to first principles. India rubber has hardly more than half the inductive capacity of gutta percha but has not made a good record for durability. It is employed in the cable connecting Toulon and Algiers but its use has been abandoned in later constructions.

Mathematical reasoning has established that the thickness of dielectric must be about one third the diameter of conductor, for the most rapid signalling, but, as this would bring into dangerous prominence the unavoidable imperfections of the former, the practice is largely in excess of this proportion. The tests then, to which a cable under construction is subject, are as follows:

The iron wire of the armor, which is sometimes procured already coated with zinc, and sometimes so treated in the cable factory, is subjected to periodical tests for tensile strength, ordinarily, once every week, which are carefully recorded. The specific conductivity of the copper wire is determined by comparison with established standards, and it is then laid into strands, (by machinery similar to that employed in making wire rope) about two nautical miles in length, and wound upon huge wooden reels and rolled away to be covered with gutta percha. This process is one of the arcana of the craft and guarded with jealous care. In general terms it consists in drawing the strand through tanks of molten gutta percha and passing it through metal dies, which are kept well lubricated and cold enough to prevent adhesion. After becoming hard it goes through a bath of fluid known as Chatterton's compound, and while yet warm receives another layer

of gutta percha applied in the same manner as before. This compound is the only thing that experience has shown to be thoroughly efficacious and reliable for intimately uniting gutta percha, and its use entails the payment of a heavy royalty. The West India cables date every misfortune from the substitution of another material in their construction, which, while it met fully all factory tests, could not resist the vicissitudes of climate. The delay caused by the making anew of faulty joints lost the expedition the best season for laying, and misfortunes followed thick and fast.

Some fifteen days after the core has been formed in the manner described, the large wooden reels upon which are wound the two mile lengths, are immersed in tanks, heated by steam to a temperature of 75° Fah., and the first complete electrical test is applied. The principal instruments used are the astatic galvanometer, the ordinary resistance coils and the condenser, all of which are mounted on a large slab covered with ebonite and sustained by piers of solid masonry. This secures freedom from tremors and thorough insulation of the apparatus, indispensable requisites for accurate tests.

The battery cells are upon platforms suspended by cords and links of India rubber, ebonite, or other insulating material, from the ceiling; which effectually precludes loss of current in their vicinity. The shape in which this record is kept is shown in Form I.

A brief notice of these columns may be necessary at this juncture. The first three explain themselves, but the four succeeding contain records from which the degree of insulation can be estimated.

The core, having its distant end insulated, is charged with the entire battery, and, after a few seconds, the galvanometer is momentarily introduced between battery and coil, and the deflection noted. It is then cut out, and at the expiration of one minute the coil is discharged through the galvanometer and the deflection again observed. It will be found to be less than the first deflection and indicates the rate of loss of charge in one minute, which measures the perfection of the insulation. The ninth column contains a record of "copper-resistance," as it is termed in shop parlance, of the coil, which is obtained by the arrangement familiarly known as the bridge. The practice is to use a single cell in this test. The entries in the right hand and last column are for the purpose of estimating that very variable quantity, the strength of the battery. The method is to charge the condenser with one cell in good condition, and discharge it through the galvanometer (and whatever additional resistance may prove necessary)—noting

carefully the deflection. Then charge the condenser with the whole battery and discharge as before. The deflection will rarely be found to be that due to the increased number of cells, and the last divided by the first will represent the number of standard cells to which the testing battery is equivalent. By the term "Constant" is meant the deflection of the galvanometer needle, produced by sending the current of one cell through a definite resistance, commonly one million ohms, which serves as a criterion for estimating other resistances.

The expressions "I. Lead" and "C. Leads" indicate insulation and the copper-resistance of the leads, which must be estimated for the reason that the core under investigation is usually removed some distance from the batteries and instruments, and must be connected with them by wires, known as *leads*, whose various resistances must be noted and separated from those that are being sought.

Form I. CORE AT 75° Fah.

No.	Length.	Weight.	N Charge.	N Disch.	P Charge.	P Disch.	1 Min.	C R	

Form II. SERVED CORE.

No.	Length.	G. P. R. per knot at 75°	N Charge.	N Disch.	P Charge.	P Disch.	1 Min.	C. R.	Temperature. Cable.	Temperature. Coil.	
											Condenser 1. 10. 200. Constant. I. Lead. C. Leads.

Form III. CABLE TEST.

No. of Section.	Length.	N Charge.	N Disch.	P Charge.	P Disch.	Deflec. after 1 min.	C R.	Rev's of Mach.	Temperature Cable.	Temperature Coil.	Last coil in circuit.	
												Condenser 1. 10. 200. Constant. I. Lead. C. Leads.

It was once deemed necessary to test cables under a pressure of many atmospheres and again in a vacuum in order to rupture bubles of air which might be confined in the dielectric; but this is now no longer the practice.

The warm bath and accompanying test being finished, the core is passed through a machine which serves it with wet hemp, and, for fear

that it may have received some mechanical injury in the process, it is again subjected to tests whose results are recorded in very similar form to the last (see Form II.); the only exception being that the insulation is obtained by the method of deflection and expressed in actual units of resistance.

The remote end of the coil being carefully insulated, it is charged with the full battery, and the galvanometer interposed between battery and cable. The only path in which a current could establish itself is through the dielectric, and the deflection of the galvanometer needle by this current, compared with its deflection through the specific resistance—in short with the constant of the galvanometer,—affords a means of expressing the resistance of the insulator to the passage of current in conventional units. If the reel of "served core," as it is now called, is satisfactory, it is immediately joined to its predecessor, which is perhaps already receiving its iron armor, and being coiled away in large water-tight iron tanks of great capacity. Each machine has its own tank, and the cable made by it constitutes a section. The process of jointing is one of greatest nicety and involves every possible precaution. The several wires of the copper conductor are made one, by solder, and an accurately fitting scarf is formed between the two ends to be united. This is served with fine wire and farther secured by solder, and, ultimately, gutta percha is drawn over the union and the ends worked and kneaded imperviously together, using the patent compound of Chatterton with lavish hand. So much trouble was encountered at these points in the earlier cables that the safeguards resorted to are most stringent. Contracts generally permit a joint to have as little as one third the insulation of other portions of the core, but a skillful manipulator will cause them even to exceed it.

The mode of testing is to immerse the joint, after cooling it thoroughly in ice, in a carefully insulated vessel of water, and, having insulated the remote end of the cable, charge it for a brief period of time. The vessel of water contains a sort of collecting plate, which is in communication with a condenser, and whatever charge percolates through the joint into the water is stored up in the condenser. After a suitable interval the condenser is discharged through the galvanometer, and the deflection noted. The same steps are then taken with a similar length of core which includes no joint, and a comparison of the deflections obtained reveals the ratio between insulation of joint and of core. A separate record of these tests is kept, each joint specified by a number, and its distance from the beginning of the cable noted.

The name of the person who made it is also entered, in order to fix the responsibility of failure, should it occur. The hemp serving is then carefully laid around the jointed core, and it passes through the machine, which applies the armor without further manipulation. The position of the joint is indicated upon the finished cable by a leather tag. The only subsequent test which is taken is that of the finished sections in the tanks. It occurs every noon at the dinner hour, when the machines stop, which in motion would interfere with the observation, and is substantially the same as the preceding. The form of record is appended. (See Form III.)

The finished cable, passing from the machine to the tanks, envelopes a drum of known circumference whose revolutions are recorded, and inspection of these dials discloses the amount completed each day. Five or six miles is the capacity per diem of the average machine. It is customary, during the process of construction of a cable, to send daily from the works to the office of the engineer, sheets drawn up in the following manner. (See Forms A. B. and C.) By reference to these he can give instant information to curious directors and stockholders *in esse* and *in posse*. The tabular forms are substantially the same, and are exhibits of all the results of the tests applied at different stages of the construction. Form A. is an abstract from the record of observation upon "core at 75," as it is familiarly called. Form B. is the same for the "served core." The weight which is noted in Form A., as a useful factor in the electrical calculation, is omitted after the serving has been applied.

"Actual Resistance" is substituted for "Total Conductivity," the one being the reciprocal of the other, and the resistance of the insulator per knot is calculated, by means of established tables, from its actual temperature, which for the "served core" may be anything. Form C. introduces quantity of finished cable, and takes note of the temperature of the dry tank in which it is being coiled, as well as of that portion of "served core," which is still in electrical connection with it; but has not yet gone through the machine which applies the armor. The resistance of the insulator for the whole length of cable in circuit is recorded, and, at first glance, seems an incongruity, as it reduces as the cable grows. Reflection shows that as no insulation is so perfect as to entirely obstruct escape, the greater length affords more avenues of exit, and two miles of similarly insulated wire offer only half the resistance of one mile. The resistance of conductor, however, varies in direct ratio to the length.

Form A. _____ *TELEGRAPH.* *No.*_____

Tests applied to Core.

DATE.	Time.	Number of Coil.	Length of Coil.		Weight of Coil in lbs.	Diff. between Real and contract Weight.		Temperature of Tank Fah.	Conductor.		Insulator.					Induction.							REMARKS.
			Yards.	N. Miles.		+	−		Total Resistance.	Reduced per N. mile.	Constant of Instrument.	No. of Standard Cells.	Deflection after 1 min. Neg.	Total Conductivity	Resistance per N. mile.	Discharge from Condenser.	Discharge from Core.	Percentage after 1 min.	Capacity of Coil. Condenser—1.	Capac. per N. mi. Condenser—1.	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

Form B. _____ *TELEGRAPH.* *No.*_____

Tests applied to Served Core.

DATE.	Time.	Number of Coil.	Length of Coil.		Temp. of Tank. Fah.	Conductor.		Insulator.							Induction.						REMARKS.
			Yards.	N. Miles.		Total Resistance.	Resistance per N. Mile.	Constant of Instrument.	No. of Standard Cells.	Deflection after 1 min. Neg.	Actual Resistance of Coil.	Resist. per. N. Mile. Observed.	Resist. per. N. Mile. Calculat'd from 75°.	Resist. per. N. Mile. At 75°.	Discharge from Condenser.	Discharge from Coil.	Percentage after 1 min.	Capacity per N. mile at Temp. Cond.—1.	Joined to Section.	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	81	19	20	21	22	23

Form C. _____ *TELEGRAPH.* *No.*_____

Tests applied to Cable. *SECTION.*_____

DATE.		Time.	No. of Coil at end of Circuit.	Total length of cable.		Length of cable complet'd		Temperature Fah.			Conductor.		Insulator.						Induction.				REMARKS.
				Yards.	N. Miles.	Rev's.	N. Miles.	Cable.	Core.	Mean.	Total Resist'ce	Per Nautical mi.	Constant of Inst.	No. of Standard Cells.	Deflection after 1 min. Neg.	Resistance of whole length	Resistance Per. N. mile.	Reduced to 75°.	Discharge from Condenser.	Discharge from Cable.	Percent'ge after 1 min.	Capacity per N. mile. Condenser=1.	
1	2	3	4	5		6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

The final step of the process is to cover the armored cable with a mixture of tar and silica as previously described, and it is then ready for shipment. This operation may go on as soon as any section of the cable is completed. It is drawn through a machine which roughly serves it with yarn, and at the same time pours upon it the molten mixture which is shaped and hardened by a die through which the cable passes.

Stowing it on shipboard is carried on in the following manner. The more tanks the vessel has the better, not only for preserving the trim while paying out, but also for convenience in "turning over" cable, as the phrase is, when it is necessary to cut out a failing joint or a local fault. These tanks are water-tight, made of boiler iron, of as great size as the beam and depth of hold will allow, and firmly secured to the ship's keelsons. In the center of each is a conical chamber equal in height to the tank, four or five feet diameter at top, and seven or eight at the bottom. The interior workmanship of tank and cone is as smoothly finished as possible, to guard against any hitch in paying out. Above each tank, during the process of stowing, a peculiar reel is placed, which draws the cable from the factory tanks through as many guide pulleys as may be necessary, and delivers it to the men stowing it below. All large cable-Works endeavor to establish themselves on the banks of navigable streams, so that the risk incurred by their perishable

Fig. II.

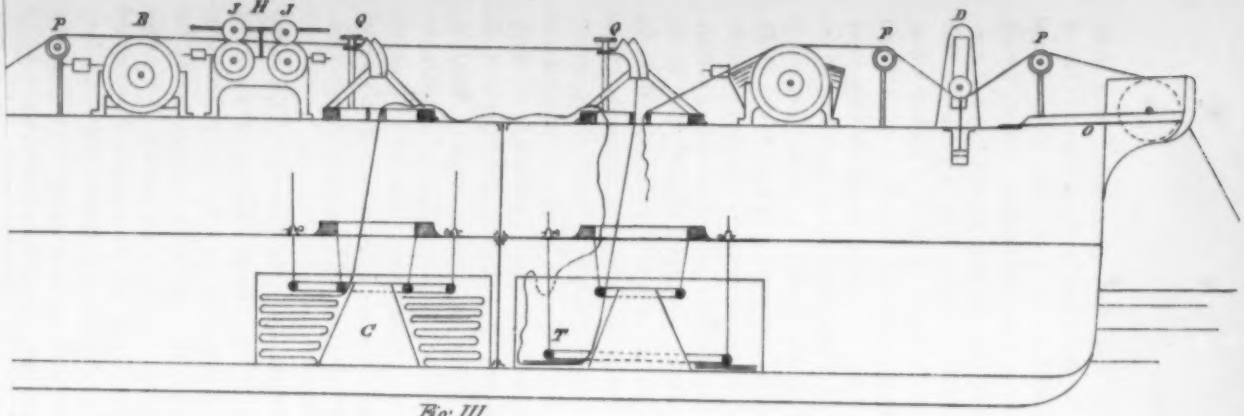
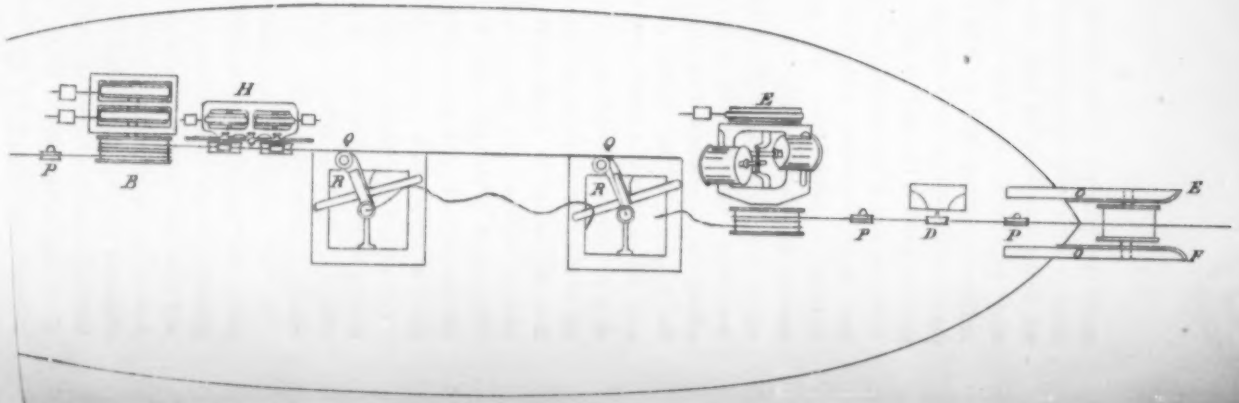


Fig. III.



staple in passing from factory to ship may be reduced to a minimum. This status facilitates immensely the coiling down. One of the little machines alluded to—which consists of little more than a wheel with an acutely angular groove scored in its face, driven by an ordinary hoisting engine, will enable skillful men to coil down a couple of miles per hour without much difficulty. The cable lies in this narrow groove, pressed down into it by what is called a jockey wheel riding on top, thus creating adhesion enough to let the grooved wheel haul along the cable at its own velocity. The cable-end, having come on board, is passed down into and over the edge of the tank—to be accessible for testing purposes. While the stowing goes on, this end is carefully insulated so that a continuous charge may be kept on the cable, the escape of which through the galvanometer would indicate to the observer the occurrence of any injury to the dielectric. The coiling is from the periphery to the centre of the tank, and from right to left, to insure its paying out naturally. And as each layer, termed a flake in shop parlance, is completed, the cable must cross it to reach the starting of the next flake, as in the sketch, Fig. I. This naturally produces inequalities in the surface, which are remedied by the introduction of battens between the flakes, radiating from cone to periphery of tank. Whitewash is liberally used to prevent the adhesion of the tar and silica coating of adjacent parts. While the coiling down is going on, there is time for a glance on deck, at the assemblage of machinery there collected. Substantially it is but an apparatus for picking-up and paying-out cable but its accessories are numerous. Two meagre views of the deck will assist description, and they are given herewith. See Figs. II & III.

At bow and stern are heavy outriggers, marked O, which carry strong flanged sheaves designated by S. These sheaves have curved guards attached, which permit the cable or grappling rope to trend in any direction, without subjecting it to sharp bends or obstructing its motion in or out, as the case may be. A practical caution is well introduced at this point, viz. to avoid the not uncommon blunder of keeping these curved guards concentric with the sheaves above the level of the outriggers. With the cable or grappling rope trending athwart-ship it is very apt, when bow or stern sinks in a sea-way, to slip up the curved guard and, remaining there, when the vessel rises to the next wave, cause damage to apparatus and cable. The next piece of mechanism which invites attention, is the dynamometer lettered D, for measuring the strain upon the cable or grappling rope at each in-

stant. Two elevated pulleys, P. P., stand at equal distances from a standard in which a carriage bearing another grooved pulley has vertical motion. The cable passes over the fixed pulleys, and under the movable one which plays the part of a rider to it. Weights are attached to the riding pulley, and its motion is steadied by connecting to it a loose piston which traverses a vertical cylinder beneath the standard, filled with oil or water. The nearer the cable approaches the line joining the vertices of the fixed pulleys, the greater will be the strain upon it, and, knowing the distance apart of the latter, and the weight of the riding pulley with its attachments, the strain corresponding to a given amount of vertical motion, may be readily calculated. Scales are constructed in this manner, and it is better that the motion of the riding pulley should be perpendicular to the line uniting the fixed pulleys.

The brake, Fig. IV., next demands notice, and consists of a heavy drum about which several turns of the cable are taken, thus obtaining the proper degree of adhesion. The first turn of cable is deflected, after completing one circuit of the drum, by a device styled a "plough edge," making room for the succeeding turn and thereby preventing fouling. The shaft which carries the drum has also upon it several heavy, broad-faced wheels which the brake blocks press against. These are commonly of elm, and attached to a belt of iron encircling the wheel in manner of the appended sketch.

The wheel turns in the direction indicated by the arrow, and if the levers are weighted too heavily, the adhesion between blocks and wheel face causes the lever to lift; thus bringing the distance upon it, between the points of attachment of the brake band, to some extent into its circumference, and the lengthening it thus undergoes releases the wheel. Notwithstanding that excess of motion in the lever is controlled by loose pistons working in cylinders filled with liquid, which terminate the rods that depend from the levers and bear the weights, the action of this arrangement is often found to be too sudden and extreme and the following device has proved a remedy, viz. dividing the brake band and attaching the adjacent ends to a common axis in the frame which supports the wheels directly opposite the fulcrum of the lever. The faces of the wheels are in the shape of an extremely obtuse angle, apex upward, to prevent lateral motion of the blocks. It is almost needless to say that the brake wheels must be immersed in tanks of water with provision for changing it often. The apparatus marked H is a dependency which fulfils precisely the same office as a man easing a taut rope by rendering it around a belaying pin. To secure adhesion to

Fig. IV

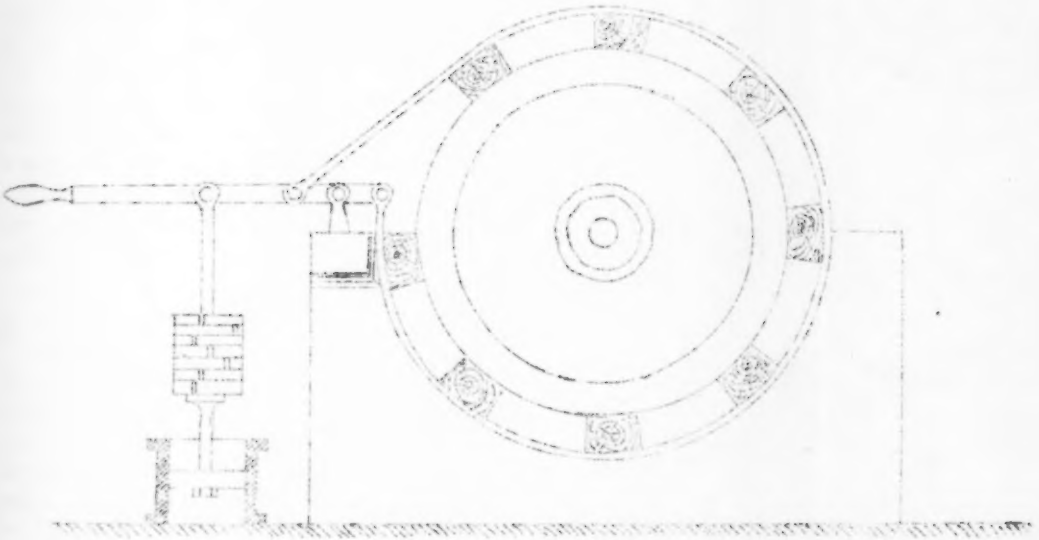


Fig. I.

the drum, the cable must be kept moderately taut behind it, and the holding-back machine does this.

The cable lies in acutely angular grooves upon the faces of wheels which have a common axis with small brake wheels. Upon the cable ride weighted jockey wheels, marked J., which crowd it down until sufficient adhesion is secured, and the cable feels the influence of the brakes.

In the center of every hatch is a species of hawse pipe, which serves to guide the cable to the upper deck, and Q designates a quadrantal cast iron trough, which leads the cable from the hatch pipe into the way which extends from the forward tank to the paying-out machinery. This may or may not be provided with rollers to ease along the cable. In the tank are seen a couple of iron rings of different diameters, one of which is capable of adjustment at any point between the top and bottom of tank.

The smaller one generally encircles the cone just below its top, and is about a foot greater in diameter, and the larger one whose diameter is about half that of the tank, follows down the cable as it diminishes. The purpose of this "crinoline" as it is called, is to confine the rapidly moving cable close to the cone and thus add to the safety of the men, who must remain in the tank during the laying, to remove the battens used in stowing the cable, and carefully guard against twists and kinks. The crinoline rings and hatch pipes are fitted with movable openings, which readily permit the cable's being withdrawn in the perilous operation of changing tanks. The picking-up machinery varies little from the foregoing.

A large strong drum fitted with powerful brakes, and driven by well sized engines is its general description. Its remoteness from the main boilers of the ship, generally necessitates a separate one for hoisting purposes, but this is not always the case. The chief desiderata are that all drums, sheaves and guide pulleys have liberal width of face, for the reason that, besides having to afford room for two parts of cable—as when a bight is hauled aboard—they must occasionally contain chains and hawsers for springs and other purposes (a group of three sheaves at the bow would at times be a great advantage); that the "balks," as the timbers supporting the bow and stern sheaves are called, have numerous heavy ring bolts for the attachment of selvagee stoppers which are used to hold the cable when necessary to remove it from the drums for any purpose: that one or more counters be attached to each drum to register its revolutions, and that in every tank, and convenient to the paying-out machine, engine-room signals be put up, to strike in event

of a threatened fouling of the cable. A spacious, convenient, and well lighted chart room on deck is indispensable, for the ship's position must be plotted continually, and the per centum of slack cable regulated by the probable depth of water there. The testing room must also be convenient, spacious and well appointed. It would be impossible in the limits of this article to specify its equipment, but it is much the same as that of the test-room of a factory. The astatic is replaced by the marine galvanometer, whose heavy turret of soft iron and controlling magnet, guards it against terrestrial disturbance, as perfectly as the double attachment of the needle does against the oscillations and shock of waves. In extreme cases it is well to substitute a strand of silk floss for the slender fibre which supports the needle. Resistance coils and a condenser, also form part and with batteries for ship and shore use, insulated wire, instruments for telegraphing, coupling screws, various implements, tabular forms and stationery the list is complete. The special equipment of a cable-ship, consists of grappling rope, grapnels, chains, huts of corrugated iron for erecting over the shore-ends, when they are in isolated regions as is generally the case, tools and material for jointing and splicing, picks and shovels for trenching, buoys and anchors of all sizes, small brakes and sheaves, for boat and barge use, and last but by no means least, a steam-launch.

Imagine a ship thus loaded, fitted and equipped, *en route* for the initial point of the cable route. This in itself is a matter for deliberation, and the choice is influenced by prevailing currents and probable weather. With a cable perfect as regards insulation and external condition —which reduces vastly the chance of sudden stoppage—it is best to run with wind and tide; and even if local faults are suspected which may develop under pressure, or if the cable has been deranged in the tank, by stress of weather, making it likely that the vessel may have to stop and remain hanging by it, while faults are cut out or a "foul flake" cleared, it is still better to run so that wind or tide will conduce to keep the ship pointed on her course, instead of swinging her back over the cable put down and subjecting it to risk of rupture across some sharp edged rock.

The surveillance maintained day and night in the factory, is not altogether relaxed on ship board. The cable tanks are kept filled with water, if weather will permit, and daily tests of insulation and continuity taken. Few tests are permissible on ship board, but these serve to demonstrate the condition of the dielectric, and the fact that the conductor is unbroken, and are the only absolutely important ones. Hav-

ing reached the initial point of the route the vessel chooses suitable anchorage while the shore end is put down. This type of cable has not been specially described, and it may not be amiss to do it here. Its weight ranges from twelve to thirty tons per mile, and is given by additional armor, each layer of wire being of larger size than the preceding one. This is used where anchors may be dropped or vessels ground upon it. The end may be made fast to a boat which is either towed or warped ashore, and, as it proceeds, the cable is lighted out of the ship and kept from sinking by boats which slip under it whenever the bight gets too heavy for the predecessor, or, if this is not practicable, a measured quantity is put in a barge or lighter, which is towed from shore to ship.

The coast of Guiana presents as great difficulties to this operation as can be imagined, and they were overcome as follows, in laying the line from Trinidad to Demerara. The shallow sea whose greatest depth was not sixty fathoms, in the whole route of three hundred miles, precluded the laying of heavy cable into deep water, and it was considered unjustifiable to carry it beyond fifteen fathoms, which was not found within eighteen miles from land. The ship having been lightened in every way that ingenuity could suggest, proceeded to the selected spot, and, having attached a buoy and anchor to the cable end, and having sealed it up, let it go, and steamed in-shore in a making spring tide. The sea bottom of all this region is a soft silt washed down by the great rivers of that coast, and a ship may ground with impunity; so she kept on till the water began to shoal, when preparation was made to buoy and let go the cable end. The moment bottom was touched, the buoy was dropped, the cable cut and sealed up as rapidly as possible, and thrown after it while the ship backed out of a nest which the turning tide was quickly preparing for her. There remained one and a half miles to overcome ere solid ground was reached, and the next step was to load a flat-bottomed scow, which was fitted with mast and sail, with the needed quantity of cable, and again to run for shore in a favoring breeze, throwing over the bights by hand. When bottom was touched, three quarters of a mile interposed between cable end and shore, of a mud too thick and tenacious for boats to move in, and too liquid to support a man's weight. The method then employed was to send from shore a grappling rope, make it fast to the cable end, and forcibly haul it through the mud. Two hundred and fifty convicts, in charge of keepers, performed this feat, either pulling on shore or lighting the cable and grappling rope along through the mud, in which

they sustained themselves by lying on floats of plank placed beneath their arms. A striking converse to this occurs in the Franco-American cable where it touches at St. Pierre. The steep sides of the island offered no natural path to the cable ends, which are therefore embedded in a trench cut in solid rock, and covered with hydraulic cement.

The "shore end" and "intermediate" cable—which are united by splicing to each the proper end of a "taper," as it is termed, made in the factory for the purpose—being disposed of, the "deep sea" cable in the various tanks is joined together, and to the "intermediate," by means of another "taper," and the laying may at once commence.

The process of "joining up," includes the making of the electrical connection already described, and the splicing together of the iron armor. The latter process is quite like splicing an ordinary iron rope. Strands in one end are unlaid, and their places supplied with strands extending from the other end. A certain alternation is observed in this, and every pair of strands is butted as far as possible from the adjacent pair. The butted ends are strongly served with wire prepared for the purpose, and the entire splice, which may be from five to ten fathoms long, is served with tarred rope yarn. Provision has meantime been made on shore for the electrical test, which is kept up during the laying, and conducted as follows:

Insulation and continuity is all that is needed, and to exhibit these at every instant on ship board, the cable end on shore is connected to one pole of a condenser, between whose other pole and the earth a speaking instrument is interposed. The same arrangement is made with the end on ship board, with the addition of putting the full testing battery in communication with the cable through the galvanometer, which consequently exhibits a permanent deflection. The amount of this deflection measures the insulation—the sudden disappearance of the light from the scale, indicates a fault for which the ship must be stopped, and the defective spot cut out. Reflection will suggest that the conductor might be parted within the dielectric, without especially disturbing the deflection, and this danger is guarded against by the transmission of signals between ship and shore, every five minutes. This does not at all interfere with the permanent charge, the method of connection making it possible to cause waves of current to pulsate through the conductor without any electricity leaving or entering it. Strict record is kept of "continuity signals," and of the deflection which naturally increases as the cable gradually changes its dry tank for the deep sea. A reference to the distance paid out, however, renders it

easily reducible to a certain deflection per knot, which is the basis of comparison.

The routine on deck consists in noting the quantity of cable paid out, and comparing it with the distance made by the ship, as deduced from the patent log, at brief intervals. The route must be shown by a vessel leading the cable ship, as the varying mass of metal on board the latter so effectually deranges the compasses that not the slightest dependence can be placed upon them. The navigator, therefore, has little more to do than to determine from the ship's position by dead reckoning, and the profile along the adopted course, what may be the inclination of the bottom with the surface of the sea, and thus estimate the suitable quantity of slack cable. The average allowance is fifteen per cent. and it is regulated by the brakes which are weighted at will. A practical caution comes in very properly at this point, which is to avoid loading the brakes with reference to maximum speed of cable—as when the stern of the vessel rises in a sea way. If this be done, the brake drum will actually stop when the stern settles down in the trough of the sea, and the cable be subjected to great risk of snapping. One of the most delicate operations of laying, is, on having finished one tank, to commence laying from another. It must be borne in mind that the bottom end of the first is connected to the top end of the second, and the bight lies along the deck between them. It passes within the crinoline and hatch pipe of the empty tank, from which it must be extricated with unerring certainty, at the critical moment, and the bight carefully handled, to prevent kinks and to guide it safely from tank to paying-out machinery. Just before this event occurs, men are stationed at the hatch, along the bight, at the brakes, and stoppers are loosely applied for emergencies. The ship is stopped, and while drifting on, the transference is accomplished.

In the event of a fault passing overboard, which is indicated by the galvanometer, the ship is instantly stopped and the distance of the fault measured. If the interruption be a failure of continuity, the distance away of the rupture may be measured by means of the recorded capacity, per knot, of the cable. Note the deflection caused by the discharge from a condenser of known capacity, and compare with it the deflection caused by a discharge from the cable, with the same battery and interval of time. If the dielectric be perforated, the distance away of the "earth," (as it is called) thus formed, may be found by measuring the resistance of the conductor to the point, by means of the "bridge" and referring it to the known resistance per knot. This

point determined, it is necessary to reel inboard again, and this is done by passing a spring from the picking up machine, through the bow sheaves, and making it fast to the cable astern. The reeling-in proceeds till the spring feels the weight, when the cable is cut at the stern, and shortly comes on board over the bow, and is secured with stoppers as soon as the "fault" is recovered. After cutting out the defective portion, the end over the stern is brought round outside the ship, and in through the bow sheaves, and the joint and splice made. A hawser is then made fast to the bight and put about the drum, the strain is taken by the drum, the stoppers are loosed, and the bight lowered by the drum till well below the hull and screw, the hawser is cut, and the cable once more hangs from the stern of the ship, which proceeds on its course. This operation is most hazardous, and attempting it in a rough sea lost both the lines from Jamaica to Aspinwall and Porto Rico. A perfect cable ship should be made after the pattern of our "double-enders," with feathering paddles, and capable of picking up or paying out at either end. The landing of the cable end is only a repetition of the work at the starting point.

Final tests, however, are made of gutta percha and copper resistance which are materially changed for the better, by the low temperature and great pressure to which it is subjected. The Atlantic cable reduced its copper resistance six per cent after laying, and increased its insulation nearly eight-fold. An apparatus which has a most important office here comes into play and demands brief notice. It is the lightning arrester, which consists generally of a pair of metal plates, bristling with points, and in near contiguity yet not touching. The cable conductor is attached to one, while the other connects by an ample earth wire with the ground. The air line is attached to the same plate as the cable, by means of an extremely fine wire, which conducts low tension currents well enough, but fuses at the attempted passage of an intense charge. If lightning strike the air line, instead of entering the cable and bursting through the dielectric to earth, it is checked by the melting of the fine wire, and, leaping across the small interval between the contiguous plates, finds ready escape to earth.

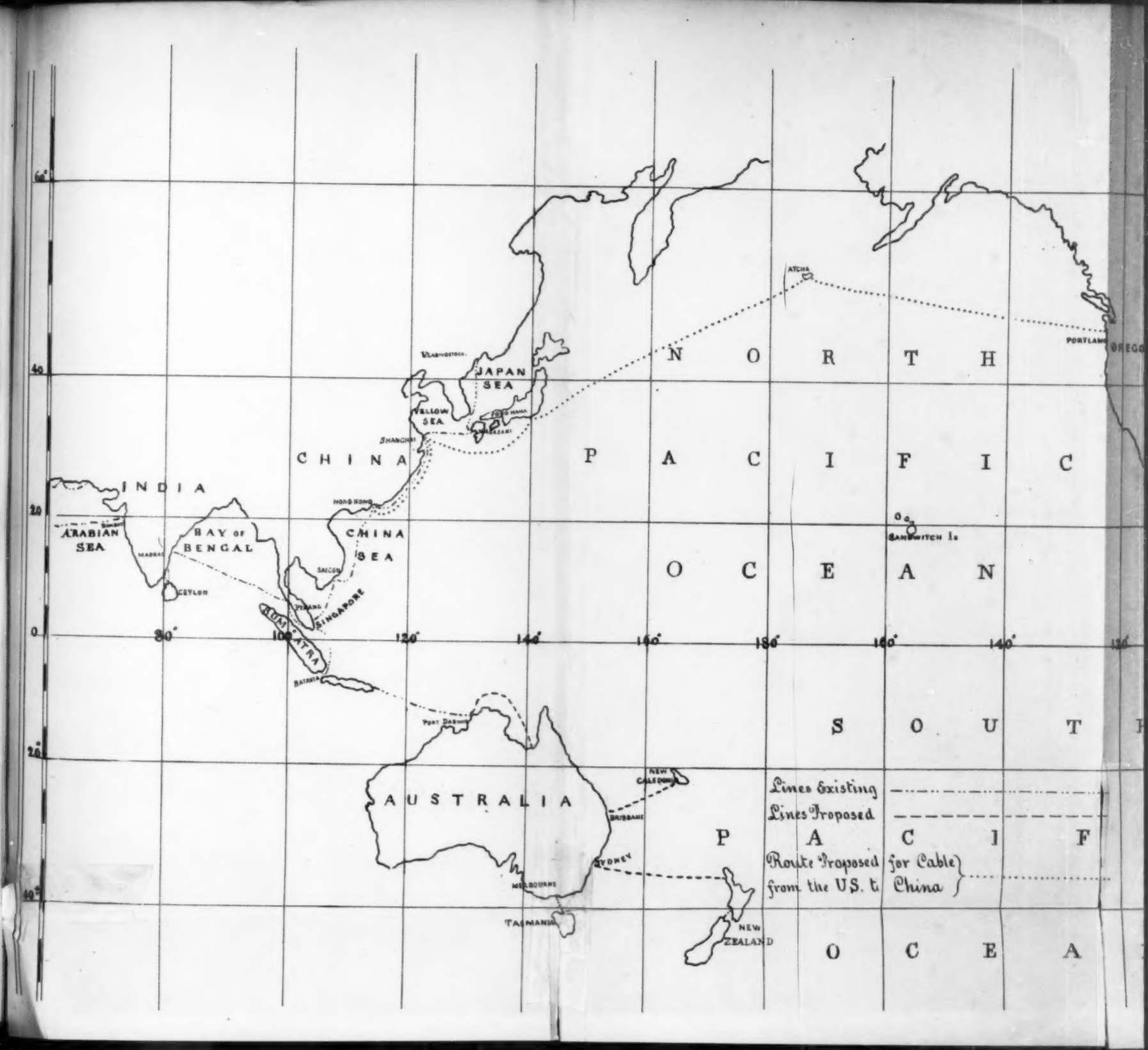
The grappling for a cable is so purely a tentative process, that it is impossible to enunciate any general rules. The major part of the work is to acquire an idea of the bottom, and to determine upon the proper implements and manœuvers. These settled, the end is well nigh reached. The apparatus consists of grapnels, whose pattern is rather a matter of caprice, chains of different sizes and lengths, and a rope made especial-

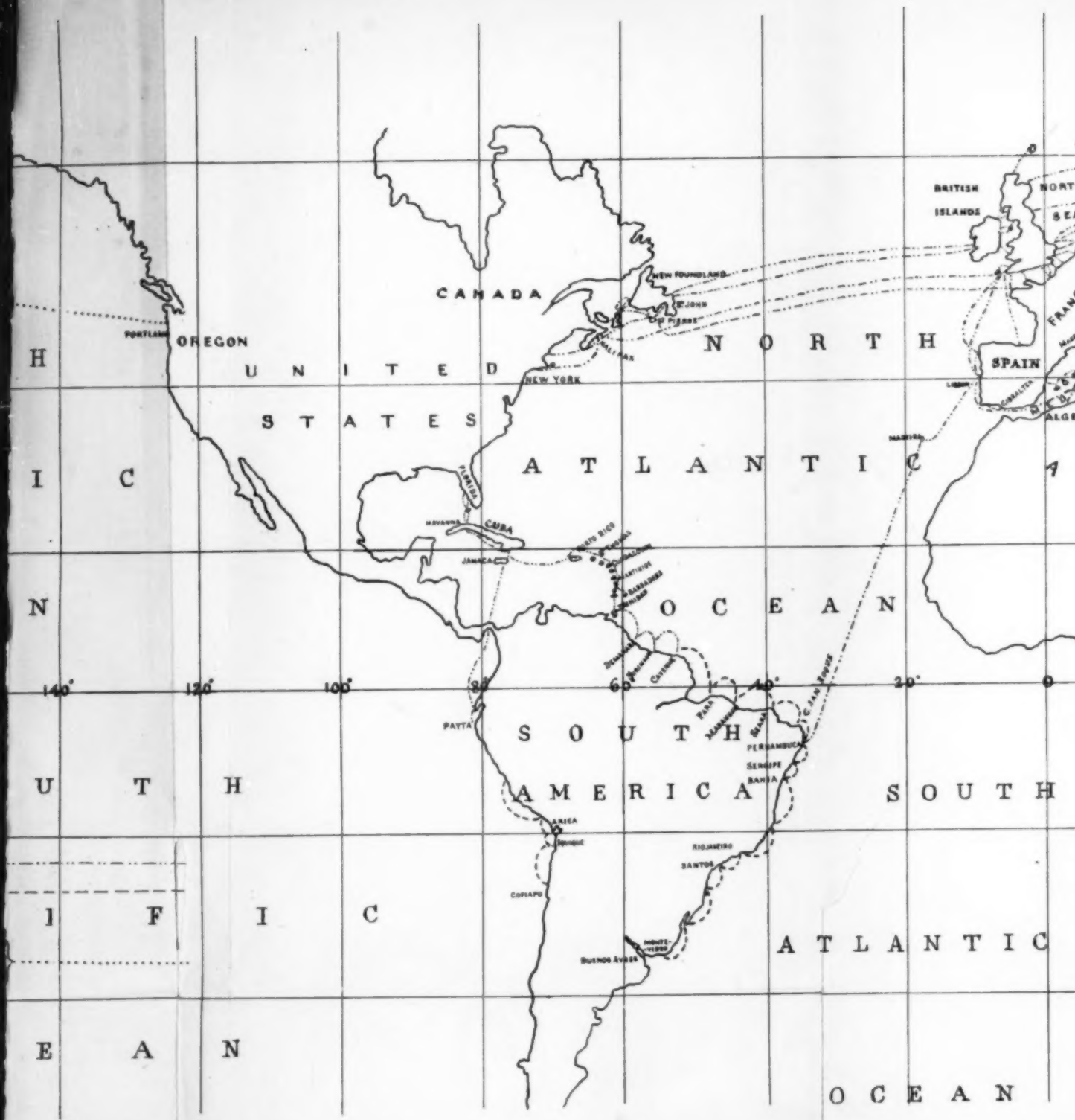
ly for the purpose, of wire and tarred hemp. Shackles and swivels of an especial pattern are also employed. The rope possesses immense strength and just the proper buoyancy; wire rope being too dead and inert, and hemp, of sufficient strength, offering too great a frontage to the current. In grappling within sight of fixed points, the search may proceed at all times—always working down wind or tide. Let there be no doubt of being well above the cable before the grapnel is let go, and that there is enough rope out. Generally speaking, the more chain that is interposed between grapnel and rope the better, as it keeps the former down to its work. Away from definite points of reference, buoys may be anchored, and their positions determined as a substitute, but they rarely watch long, and the best method seems to be to move toward position, with the hope of being on it at a convenient hour for a good observation, and to so forecast that the termination of a drag shall fall in a time suitable for another, and in this manner make it possible to plot the approximate drift of the ship. It saves going over explored ground. The grappling rope leads through the forward dynamometer to the picking up machine, and the indications of the former are carefully watched—any sudden increase of strain denoting that the ship is brought up by something which must be investigated, ere the work can proceed. The tremor of the rope also reveals much to an experienced touch. In deep water to attempt to drag otherwise than with the current is futile. It was supposed that twin screws would prove of great advantage to cable ships in this respect, but experience has not so demonstrated. Even with a slender rope, the centre of pressure of current, upon the rope and ship combined, falls far below the hull, when the depth of water is great, and although twin screws may lay the ship's stern across the current, the general drift is not appreciably altered. In all cases the use of engine power in dragging is to be discouraged, if any other expedient can be found; the risk of severing the cable is very great. Underrunning is resorted to reluctantly: with uniform bottom it may be carried on successfully, but the impossibility of ensuring that the ship keep directly over the cable, involves the risk of snapping it around or under some projecting rock, which it may encircle.

Work of the kind just described is necessitated by accident in laying or by the interruption of an established cable, and in the latter case is preceded by careful tests from both ends. The distance to the escape is best found by means of the "bridge" and the recorded resistance of the conductor: if the conductor alone be broken, the capacity test

will locate it. Other tests are prescribed, but are of doubtful utility, although the house over the end of a telegraph cable ought to afford nearly as great facilities for testing as does a factory. While the grappling is going on, a speaking instrument is connected with the cable end, and a constant watch kept upon it for news of the success of the search. This enables the ship, after having brought the cable to the surface, to know beyond shadow of doubt on which hand the interruption lies. As regardsthe method of signalling; in long circuits, this is effected by means of the mirror instrument, which deflects a pencil of light upon a screen, moving it right and left, as currents come and go, around the magnet. A perverse influence, called induction, makes itself so palpable on long circuits that the difficulty of signalling is great and speed is impossible. Analogy is often the best explanation, and an elastic tube of India rubber, traversed by a current of water, affords a capital one. Imagine such a tube conveying signals by the dropping of definite quantities of water out of its remote end—the amount being regulated by opening and closing a valve at the other. The pressure of the current distends the tube, and the closing of the valve does not instantly check the escape at the far end, for it is prolonged by the contraction of the tube, and in the case of rapid signalling would extend into the succeeding discharge effectually obliterating all distinctness. In this manner does the slow discharge from a cable militate against speedy communication. To send a signal through the Atlantic cable and to leave it clear for a succeeding one requires six or seven seconds and as this would prescribe the speed for all instruments whose indicators must move from and return to a certain fixed point under each electrical influence—as is the case with land lines—it became necessary to surmount this obstacle. The mirror instrument does not surmount but evades it, in that its motion to right and left need not be referred to any zero point but only to its predecessor, thus enabling one signal to tread upon the heels of another. The light wanders aimlessly all over the scale to a casual observer; but the trained eye interprets every movement with ease.

The accompanying map shows all existing and contemplated submarine telegraphs which have developed from the petty germ sown less than forty years ago in the English Channel. "Lines proposed," are so rapidly merging into "lines existing," that the geographer is allowed no respite in revising his charts. The one shown needs no explanation, but may suggest the question—"why should the proposed line between the United States and China follow the remote course it does,


JAPAN SEA
YELLOW SEA
CHINA SEA
ARABIAN SEA
BAY of BENGAL
INDIA
CEYLON
SINGAPORE
SUMATRA
AUSTRALIA
TASMANIA
NEW ZEALAND
NORTH PACIFIC OCEAN
SOUTH PACIFIC OCEAN
Lines Existing
Lines Proposed
Route Proposed for Cable from the U.S. to China
80°
100°
120°
140°
160°
180°
160°
140°
0
20
40
60


CANADA
NEW FOUNDLAND
ST JOHN
ST PIERRE
HALIFAX
NEW YORK
PORTLAND
OREGON
UNITED
STATES
NORTH
ATLANTIC
OCEAN
BRITISH
ISLANDS
SPAIN
LISBON
GIBRALTAR
MADEIRA
FLORIDA
HAVANA
CUBA
JAMAICA
PORTO RICO
MARTINIQUE
BARBADOES
TRINIDAD
CAYENNE
PARA
MARANHAM
BRAZIL
S. JAGO
PERNAMBUCO
SERGIPE
BAHIA
PAYTA
SOUTH
AMERICA
ARICA
IQUIQUE
COPIAPO
RIO JANEIRO
SANTOS
BUENOS AYRES
MONTE-VIDEO
PACIFIC
ATLANTIC
OCEAN
140°
120°
100°
80°
60°
40°
20°
0

SWEDEN
NORTH SEA
RUSSIA
FRANCE
PRUSSIA
AUSTRIA
TRIESTE
ITALY
TURKEY
BLACK SEA
ALGERIA
MALTA
MEDITERRANEAN SEA
ALEXANDRIA
SUEZ
EGYPT
ARABIA
PERSIA
BASRA
PERSIAN GULF
BUSHIRE
JASK
INDIA
BOMBAY
ADEN
ARABIAN SEA
BAY OF BENGAL
NAGPUR
CEYLON
SIAM
BANGKOK
G. of SIAM
PENANG
SUMATRA
JAVA
CHINA
YELLOW SEA
SHANGHAI
HONG KONG
CHINA SEA
MAURITIUS
NATAL
INDIAN OCEAN
AUSTRALIA
0
20°
40°
60°
80°
100°
120°
60°
40°
20°
0
20°
40°

instead of touching at so noted a port of call as the Sandwich Islands?" The reason is that the indicated direction is approximately the arc of a great circle and reduces the quantity of cable necessary; also, that the depth of the central Pacific is as great, or greater, than any sea of the globe. While depth does not materially enhance the difficulty of laying a cable, it increases vastly the labor of repairing one; and as this necessity is always possible, it has influence in the selection of a route. The commercial and technical aspects of such enterprizes are as full of interest as they are various. The astronomer and geographer fix localities by the tenuous filament, and the minister in his cabinet handles fleets and armies at the very antipodes; but there is yet a broader view of their influence which it is impossible to overlook. It is a grand thought to the alien that it will bear his appeal from the uttermost parts of the earth to his own people, and speed back the words that secure him safety and comfort; it has yet a nobler mission. Ethnologists declare that race peculiarities are the outgrowth of climate, soil and diet, which in numberless generations have evolved a type; that the remote and less accessible regions exhibit typical traits in marked distinctness; while rivers or other natural highways help to obliterate them by facilitating association, exchange of product, intermarriage, and other modifying influences. Is it far fetched to draw a parallel between the material and immaterial, and urge that these highways of thought are tending to assimilate mankind; to subdue ignorant envy and hatred; soften natural asperities; broaden, liberalize and mould the creature, into some semblance of that Creator to whom time and space are as nothing.